

Water status of bare-root seedlings of Chinese fir and Masson pine

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Abstract: Water relation parameters of bare-root seedlings of Chinese fir (*Cunninghamia lanceolata* Hook.) and Masson pine (*Pinus massoniana* Lamb.) were measured and changes of root growth potential as well as field survival rate of both species were studied after the bare-root seedlings were exposed in a sunny field condition. The results showed that Masson pine had a lower osmotic potential (-2.07MPa) at turgor loss point and at full turgor (-1.29MPa), compared with Chinese fir (-1.80MPa and -1.08MPa respectively). The parameter V_p/V_0 (63.27%) of Masson pine was higher than that of Chinese fir (58.03%). This means that Masson pine has a stronger ability to tolerate desiccation, compared to Chinese fir according to analysis of above water relation parameters. Root growth potential and field survival rate decreased with prolonging duration of exposure. The field survival rate of both species was reduced to less than 40% after the seedling being exposed only two hours. Water potentials of -1.60MPa and -1.70MPa were suggested to be critical values for Chinese fir and Masson pine respectively in successful reforestation.

Keywords: Chinese fir; Masson pine; Water relations; Seedling desiccation; Water potential; Root growth potential

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Introduction

Water status is one of the most common limiting environmental factors for plant growth. Low survival rate and poor growth status may be due to many biotic and abiotic factors, but Burdett (1990) as well as Margolis & Brand (1990) presented that the survival rates and growth status of transplant seedlings were primarily affected by water stress. Successful afforestation, therefore, depends on the capacity of the plant's roots to absorb sufficient water to compensate for water lost in transpiration. Plants may lose water at many stages in complex handling chains and, even in the simplest system, there is a risk of desiccation when seedling is lifted, handled and planted. This situation is especially prevalent in China because most of seedlings are bare-root and seedling handling chains are completed almost wholly by hand.

Root desiccation during handling has shown to decrease survival rate of many afforestation species such as Sitka spruce and Douglas fir (McKay *et al.* 1997; Tabbush 1987), loblolly pine (Feret *et al.* 1985), ash and birch (Insley *et al.* 1985). Hermann (1967) found that after 30-, 60- and 120-min exposure of Douglas fir seedlings in January at 32°C significantly, their survival rates decreased to 90%, 80% and 50% respectively. Tabbush (1987) pointed out that exposure time for 3 h and 18 min not only decreased sur-

vival rate of Sitka spruce to 68% but also significantly decreased height growth after two years, and the damaged plants were identified at the time of planting by testing water potential.

The pressure-volume technique, developed by Scholander *et al.* (1964, 1965), has been widely used for studying the water relations of higher plants (Tryee *et al.* 1972; Tryee *et al.* 1978; Seiler *et al.* 1990). It can be used for determining several useful parameters of water relation applied to expressing different abilities of water stress tolerance in different species (Tryee *et al.* 1972; Tryee *et al.* 1978) and also be used for seedling quality evaluation.

Chinese fir (*Cunninghamia lanceolata* Hook.) and Masson pine (*Pinus massoniana* Lamb.) are two main afforestation species in southern China, accounting for about 90% of the planting programs each year. Most of seedlings are bare-root because they grow in warm climate conditions. Although these two species are generally considered easy to be established, compared with many broad leaf species, there still exists poor survival rate and growth because of many harmful factors during period of lifting, handling and planting. Seedling desiccation in the handling chains may be one of the key factors that cause failure of afforestation. The purpose of this research is to study the effect of desiccation on root growth potential and field survival rates of Chinese fir and Masson pine as well as their ability to tolerate desiccation, and, possibly to give a threshold of water potential in practice.

Materials and methods

Plant material

One-year-old bare-root seedling of Chinese fir and

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Masson pine grown at Xiashu Forest Farm of Nanjing Forestry University in 1999 were sampled on February 20, 2000 for the experiment.

Determination of water relation parameters

Ten fresh seedlings sampled on the day before testing were cut from the root collar. The stems were soaked in the fresh water over night to absorb water fully to saturation point, and then water relation parameters were tested by using Tyree and Hammel's (1972) method.

Seedling desiccation treatments

Total of 420 seedlings for each species were randomly selected and separated into 7 groups (60 plants for each group, put in a big plastic box) to conduct a natural exposure treatment for seedling desiccation. Each seedling was separately put in the sunny field condition (Table 1) at 9:00 am. The exposure time for different groups of seedlings is as follows: 0, 0.5, 1, 2, 4, 6, 7 h. The seedlings were weighed immediately after each exposure treatment for a house so that the rate of water loss could be calculated. After each exposure treatment, 5 seedling shoots were randomly chosen to test water potential by using a pressure chamber (model ZLZ-5 made by Lanzhou University, China).

Table 1. The weather conditions during exposure time

Time	Exposure time/h	Temperature /°C	Relative humidity (%)
9:00	0	7	80
10:00	1	8	78
11:00	2	10	75
12:00	3	12	70
13:00	4	15	67
14:00	5	16	65
15:00	6	14	68
16:00	7	12	70
17:00	8	10	72

Test of root growth potential

In order to test root growth potential after exposure, 175 treated (including exposure and weighting) seedlings (25 plants for each group) were put in a round plastic bucket (40 cm in height and 30 cm in diameter) with small holes at the side and bottom. Growth media in the bucket was fine sand sterilized. The buckets were put in a controlled greenhouse to test seedling root growth potential. In the greenhouse, the temperature of daytime (8:00 a.m.-6:00 p.m.) is $(22 \pm 3)^\circ\text{C}$, and temperature of Night (6:00 p.m.-8:00 a.m.) is $(16 \pm 3)^\circ\text{C}$; relative humidity is 70-80% and Light is natural sunlight. For the duration of testing, plants were watered everyday but not fertilized.

Both Chinese fir and Masson pine seedlings grew for 35 days in the greenhouse. At the end of this period, Seedling roots were carefully washed free of the planting medium. Total number of New Roots (TNR) was manually counted

as an expressive index of Root Growth Potential.

Field performance test

Totally 210 treated seedlings (30 plants for each group) were promptly planted in a well-prepared site in the Xiashu Forest Farm of Nanjing Forestry University. The field survival rate was investigated in three months after planting.

Results

P-V curve of Chinese fir and Masson pine

The cumulative weight of water and inverse pressure of balance were measured and calculated based on Tyree and Hammel's method (Tyree *et al.* 1972, 1978). The P-V curve was drawn as shown in Fig. 1 and Fig. 2.

In Fig. 1 and Fig. 2, several important water relationship parameters can be determined for both Chinese fir and Masson pine by using Cheung's (1975) method.

From Table 2, Masson pine has lower osmotic potential (-2.07MPa) at turgor loss point than Chinese fir (-1.80MPa). This means that the drought resistance of Masson pine is stronger than Chinese fir because seedlings with low osmotic potential at turgor loss point (Ψ_{TLP}) can maintain longer turgor under water stress than seedlings with high Ψ_{TLP} (Abrams 1988; Choi 1992).

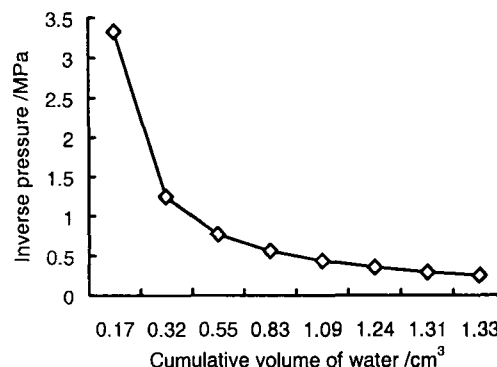


Fig. 1 P-V curve of Chinese fir

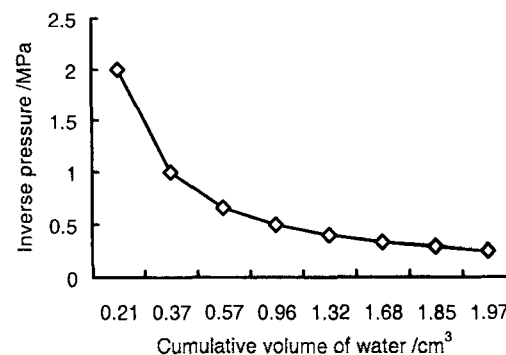


Fig. 2 P-V curve of Masson pine

Another important water relation parameter is osmotic potential at full turgor (Ψ_0). The results showed that Masson pine has lower osmotic potential at full turgor (-1.29MPa) than Chinese fir (-1.08MPa). This further confirmed that Masson pine's drought resistance is much

higher than that of Chinese fir. Cheung *et al.* (1975) found that the lower the value of osmotic potential at full turgor, the higher the drought resistance of seedlings.

From Table 2, it can be seen that Masson pine has a higher V_p/V_0 (63.27%), compared to Chinese fir (58.03%). This means that the tissue of Masson pine can retain more water than that of Chinese fir at turgor loss point. The

value of difference between Ψ_0 (MPa) and Ψ_{TLP} (MPa) of Masson pine is a slightly higher than that of Chinese fir, which means that Masson pine has lost more water before reaching the turgor loss point. This further confirms that Masson pine has higher capability of osmocondition than that of Chinese fir.

Table 2. Some important water relation parameters of Chinese fir and Masson pine

Species	Ψ_0 /MPa	Ψ_{TLP} /MPa	V_p /cm ³	V_0 /cm ³	$\Psi_0 /(\text{MPa} - \Psi_{TLP})$ /MPa	V_p/V_0 (%)
Chinese fir	-1.08	-1.80	0.829	1.975	0.72	58.03
Masson pine	-1.29	-2.07	0.955	2.600	0.78	63.27

Notes: Ψ_0 (MPa): osmotic potential at full turgor; Ψ_{TLP} (MPa): osmotic potential at turgor loss point; V_0 (cm³): symplastic volume at full turgor; V_p (cm³): symplastic volume at turgor loss point.

Effects of exposure time on water potential

The results showed that water potential decreased with prolongation of exposure time, but the change of water potential is a curve instead of a straight line. The water potential decreased rapidly at early stages of exposure and slowly thereafter (Fig. 3).

The relationship between water potential and water loss rate

The water potential and water loss rate are two different terms. In Fig. 3 and Fig. 4, the water potential decreased more rapidly than water loss rate at the early stages of exposure. But water loss rate went down more rapidly than water potential at the final stages.

The relationship between water potential and root growth potential as well as field survival rate of Chinese fir and Masson pine

Water status is one of the most important factors affecting new root growth. Our experimental results showed that root growth potential and field survival rate of Chinese fir and Masson pine decreased as water potential decreased (Table 3). The field survival rate of both species decreased to less than 40% after exposure time for only two hours.

Discussion

Osmotic potential at turgor loss point

Osmotic potential at turgor loss point is one of the most important water relation parameters. It is also a good indicator of drought resistance. Seedlings with low osmotic potential at turgor loss point (Ψ_{TLP}) can maintain longer turgor under water stress than seedlings with high Ψ_{TLP} (Abrams 1988; Choi 1992). This means that the lower the value of osmotic potential at turgor loss point, the higher the drought resistance of seedlings. The results showed that Masson pine had lower osmotic potential at turgor loss point than Chinese fir (Table 2). Therefore, the drought resistance of Masson pine is stronger than that of Chinese fir. This may be the reason that Masson pine has higher field survival rate after planting at dry sites.

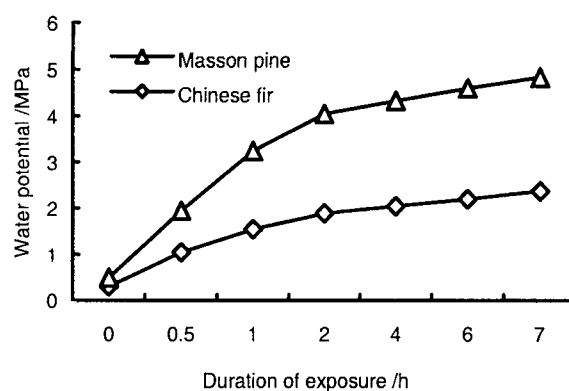


Fig. 3 Effects of desiccation on water potential of Chinese fir and Masson pine

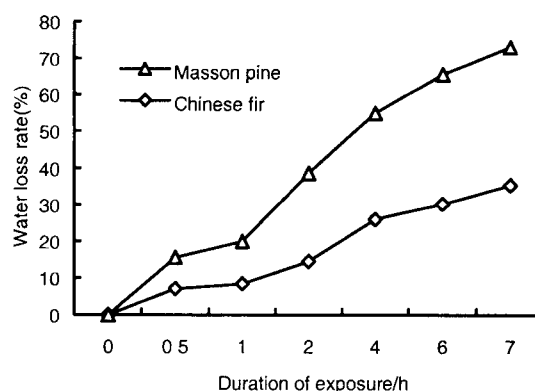


Fig. 4 Water loss rate of Chinese fir and Masson pine during exposure

Osmotic potential at full turgor

According to Cheung *et al.* (1975), if plants have low osmotic potential at full turgor, they can normally survive at a dry site, because cell elongation still occurs even in dry conditions. This is very important for plants with drought resistance. Therefore, higher drought resistance of Masson pine could be confirmed by its lower osmotic potential at full turgor (Table 2).

Table 3. Effect of exposure time on root growth potential and field survival rate of Chinese fir and Masson pine

Time/h	Chinese fir			Masson pine		
	Water potential /Mpa	TNR	Field survival rate (%)	Water potential /Mpa	TNR	Field survival rate (%)
0 (control)	0.30	26.72	95.30	0.20	78.36	95.80
0.5	1.05	12.92	90.00	0.90	66.44	90.20
1	1.55	15.76	85.60	1.70	59.04	81.40
2	1.90	7.16	40.30	2.15	41.16	45.00
4	2.05	8.68	32.00	2.28	15.16	30.50
6	2.20	5.72	19.70	2.40	9.36	8.70
7	2.38	3.36	8.10	2.45	4.16	0.00

Notes: TNR is total number of new roots.

Other water relation parameters

From Table 2, Masson pine has a higher V_p/V_0 , which means that the tissue of Masson pine can retain more water than that of Chinese fir at turgor loss point. General speaking, the water retention of a plant at turgor loss point is correlated with the osmocondition of a plant (Cheung *et al.* 1975). Therefore, it can be concluded that Masson pine has higher osmocondition than Chinese fir. Seedling water potential will change under desiccation conditions. However, The rate of change between osmotic potential and pressure potential is different. With a major change in pressure potential, the change of osmotic potential will be minor. This means that the tissue of a plant can retain much water. The difference between Ψ_0 (Mpa) and Ψ_{TLP} (Mpa) was a good indicator of relative quantity of osmotic water loss (Cheung *et al.* 1975). Table 2 showed that Masson pine has a slightly higher value of the difference between Ψ_0 (Mpa) and Ψ_{TLP} (Mpa), compared to Chinese fir, which means that Masson pine has lost more water before reaching the turgor loss point than Chinese fir. This further confirms that Masson pine has higher osmocondition than Chinese fir.

Effects of exposure time on water potential, root growth potential and field survival rate

Water loss from bare-root seedling during handling chains occurs easily. The results showed that Chinese fir seedlings lost 14.5% of water after 2-h exposure and their water potential decreased to -1.90 Mpa. In this case, the TNR of Chinese fir was below 10 and field survival rate was only 40.3%. Masson pine decreased more rapidly in water potential (Table 3), but it seems to have greater ability to tolerate water loss, because its large decrease of TNR appeared after 4-h exposure in which water potential of Masson pine decreased to -2.28 Mpa. However, Masson

pine had low field survival rate too. This seems to confirm that the water stress tolerance of Masson pine is slightly better than that of Chinese fir, and that it is very important in both species to prevent water loss during handling. As suggested by Tabbush (1987), the survival rate of Sitka spruce transplants will be reduced to 68% after exposure time for 3 hours and 18 minutes and this kind of damage could not be reversed. Therefore, Keeping seedlings moist is a key factor of successful afforestation. Lopushinsky (1990) reviewed the literature on water potential in bare-root seedlings, and concluded that leaf water potential should remain above -2 Mpa throughout the period from lifting to replanting. McKay (1997) also noted that desiccation stress between lifting and planting was a major factor influencing nursery stock survival and growth.

Many researches have tried to provide a threshold of water potential that can be easily used in practice, but species differ in the extent of root desiccation in a given treatment (Tabbush 1987; Sharpe *et al.* 1992; McKay *et al.* 1997). Furthermore, some studies suggested that survival rate decreased gradually as exposure time increased with no obvious critical level (Feret *et al.* 1985; Tabbush 1987). In such cases, the concept of a critical threshold from a biological point of view is questionable. Regardless, it is a practical necessity to give a threshold of water potential for planting both Chinese fir and Masson pine seedlings, because many afforestation failures are due to seedling desiccation, and the problem could be partly solved if a practicable standard was provided for seedling water status. The value of a threshold depends on the relationship between water potential and field performance. It is proposed that both Chinese fir and Masson pine seedlings can be graded to the following three levels according to water potential based on the real situation of Chinese reforestation practice in Table 4.

Table 4. The reforestation threshold of water potential in both Chinese fir and Masson pine

Species	Top level	Middle level	Low level
Chinese fir	$\Psi_w > -1.00(\text{Mpa})$	$-1.00(\text{Mpa}) > \Psi_w > -1.60(\text{Mpa})$	$-1.600(\text{Mpa}) < \Psi_w$
Masson pine	$\Psi_w > -1.00(\text{Mpa})$	$-1.00(\text{Mpa}) > \Psi_w > -1.70(\text{Mpa})$	$-1.70(\text{Mpa}) < \Psi_w$

The top level of seedling can be used without condition and this level should be a threshold for successful affore-

station. The middle level may be used in some special situations.

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References

- Abrams, M.D. 1988. Sources of variation in osmotic potentials with special reference to North American tree species [J]. *For. Sci.*, **34**:1030-1046.
- Burdett, A.N. 1990. Physiological processes in plantation establishment and the development of specifications for forest planting stock [J]. *Can. J. For. Res.*, **20**: 415-427.
- Cheung, Y.N.S., Tyree, M.T. and Dainty, J. 1975. Water relation parameters on single leaves obtained in a pressure bomb and some ecological interpretations [J]. *Canadian Journal of Botany*, **53**: 1342-1346.
- Choi, H.S. 1992. Variation in water potential components among half-sib families of shortleaf pine (*Pinus echinata*) in response to soil drought [J]. *Can. J. For. Res.*, **22**: 111-116.
- Feret, P.P., Kreh, R.E. and Mulligan, C. 1985. Effects of air drying on survival, height and root growth potential of loblolly pine seedlings [J]. *Southern J. Appl. For.*, **9**: 125-128.
- Hermann, R.K. 1967. Seasonal variation in the sensitivity of Douglas fir seedlings to exposure of roots [J]. *For. Sci.*, **13**: 140-149.
- Insley, H. and Buckley, G.P. 1985. The influence of desiccation and root pruning on the survival and growth of broadleaved seedlings [J]. *J. Hort. Sci.*, **60**: 377-387.
- Lopushinsky, W. 1990. Seedling moisture status [C], pp. 123-128. In: Rose, R., Campbell, S.J. and Landis, T.D. (Eds) *Target Seedling* Symposium, Proceedings, Combined Meetings of the Western Forest Nursery Associations. USDA Forest Service General Technical Report RM-200.
- Margolis, H.A. and Brand, D.G. 1990. An ecophysiological basis for understanding plantation establishment [J]. *Can. J. For. Res.* **20**: 375-390.
- McKay, H.M. 1997. A review of the effect of stresses between lifting and planting on nursery stock quality and performance [J]. *New Forests* **13**: 369-399.
- McKay, H.M. and White, I.M.S. 1997. Fine root electrolyte leakage and moisture content: indices of Sitka spruce and Douglas fir seedling performance after desiccation [J]. *New Forests*, **13**: 139-162.
- Scholander, P.F., Hammel, H.T. Hemmingsen, E.A. *et al.* 1964. Hydrostatic pressure and osmotic potentials in leaves of mangroves and some other plants [J]. *Proc. Natl. Acad. Sci. (USA)*, **51**: 119-125.
- Scholander, P.F., Hammel, H.T. Bradstreet, E.D. *et al.* 1965. Sap pressure in vascular plants [J]. *Sciences (Wash.)*, **148**: 339-346.
- Seiler, J.R. and Cazell, B.H. 1990. Influence of water stress on the physiology and growth of red spruce seedlings. *Tree Physiology* **6**: 69-77.
- Sharpe, A.L. and Mason, W.L. 1992. Some methods of cold storage can seriously affect root growth potential and root moisture content and subsequent forest performance of Sitka spruce and Douglas fir transplants [J]. *Forestry*, **65**: 463-472.
- Tabbush, P.M. 1987. Effect of desiccation on water status and forest performance of barerooted Sitka Spruce and Douglas fir transplants [J]. *Forestry*, **60**(1): 31-43.
- Tyree, M.T., and Hammel, H.T. 1972. The measurement of the turgor pressure and the water relations of plants by the pressure-bomb technique [J]. *Journal of Experimental Botany*, **23**(74): 267-282.
- Tyree, M.T., MacGregor, M.E. and Petrov, A. *et al.* 1978. A comparison of systematic errors between the Richards and Hammel methods of measuring tissue-water relations parameters [J]. *Canadian Journal of Botany*, **56**: 2153-2161.